Improvements to the IPPP toolbox

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FIRST TF

SYRTE l'Observatoire de Paris | PSL

SYstèmes de Référence Temps-Espace

Exploring the Core of IPPP Advancements

Understanding IPPP → Refines PPP by resolving carrier-phase ambiguities to integers, enhancing time accuracy.

IPPP Toolbox Enhancement → Details front-end refinements for result display, back-end bug fixes, and adaptability for external users.

Phase Jump Detection → Outlines methods for detecting phase jumps to maintain the integrity of time transfer.

Future Implementations and Collaborations → Explores Galileo integration and enhanced compatibility with OP, alongside IPPP solution comparisons across various software solutions.

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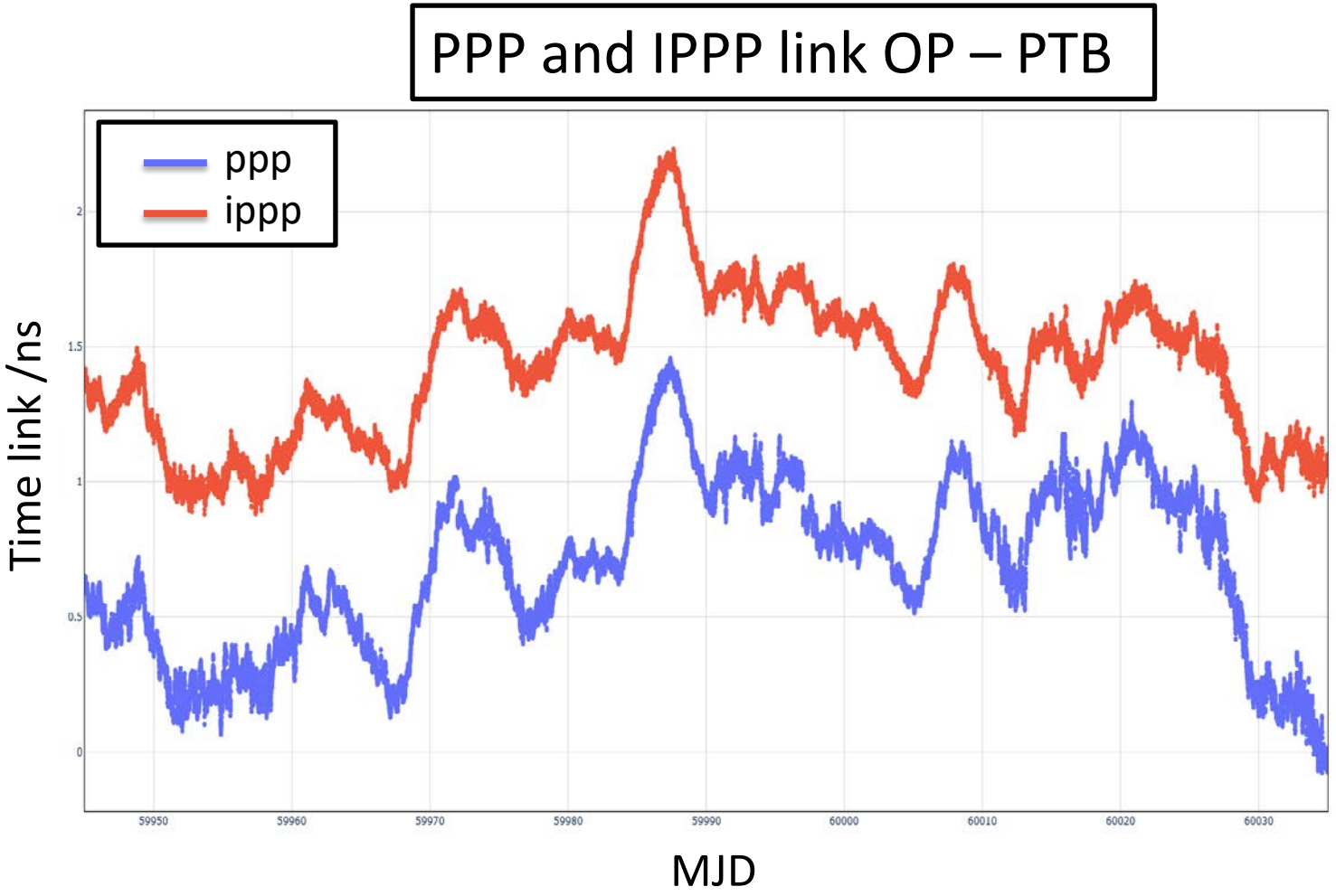
Introduction to IPPP & Distinctions from PPP

- IPPP refines PPP by resolving phase ambiguities as integers.
- Enhances time transfer stability, reducing long-term noise.
- Achieves frequency transfer sub 1e-16 accuracy after one week (*Petit, G. (2021). Sub-10–16 accuracy GNSS frequency transfer with IPPP*)



2023 January – March: 90 days

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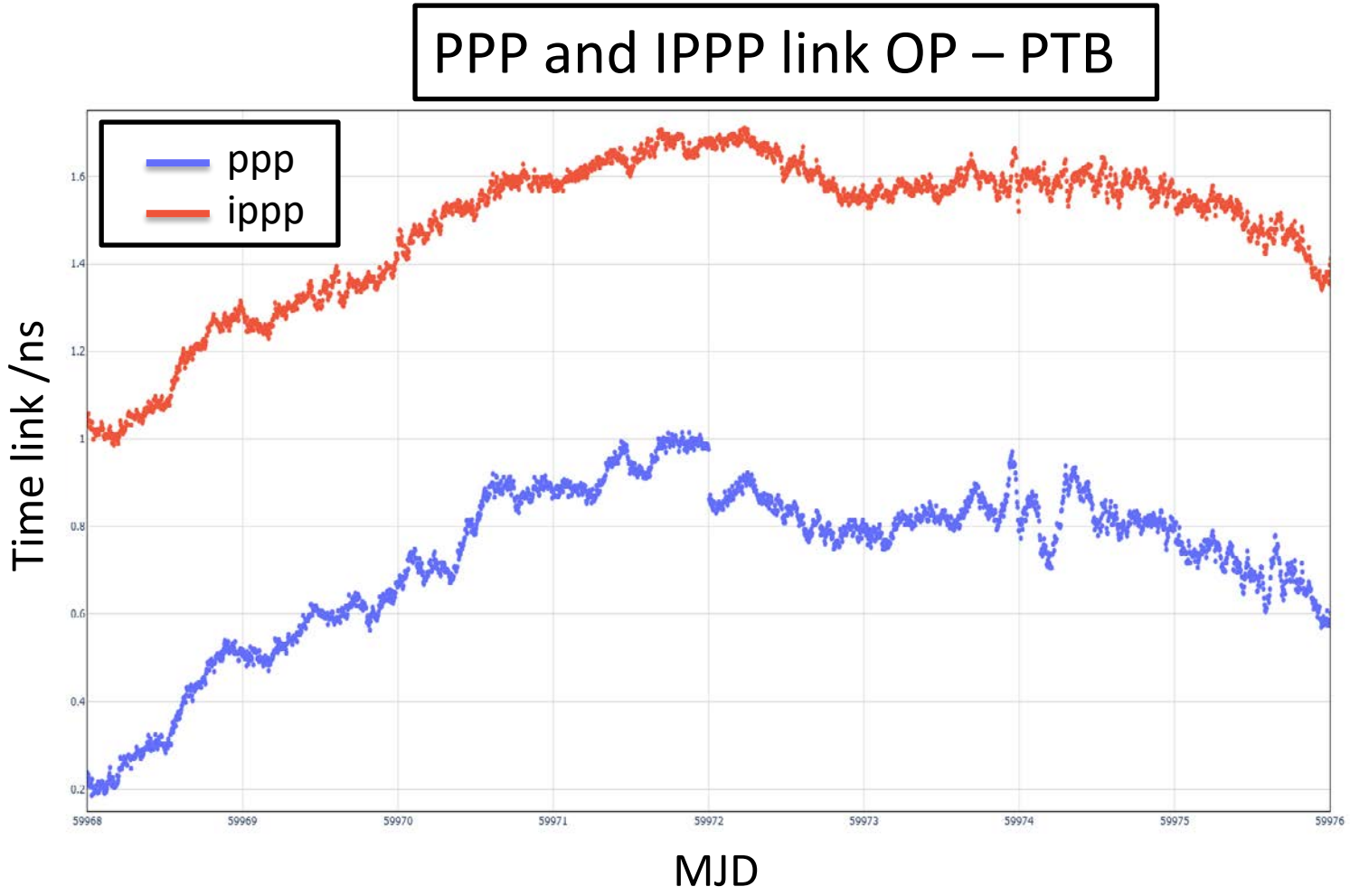

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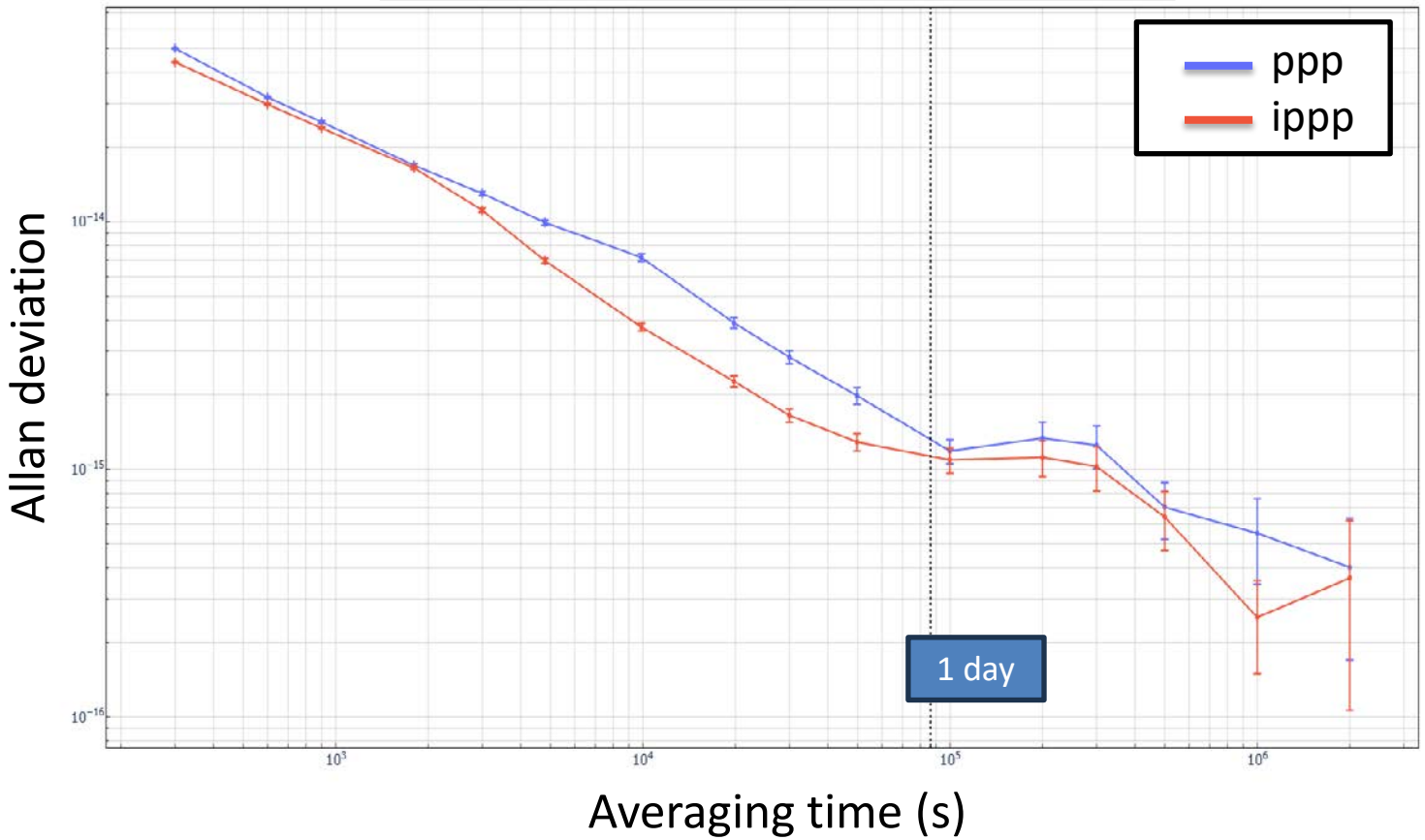
PPP and IPPP link OP – PTB



@1 day: ppp: 1.19e-15 ippp: 1.09e-15
@11.5 days: ppp: 5.52e-16 ippp: 2.52e-16

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Processing and Practical Application of IPPP

Zero-difference widelane identification

$$N_W = f(P1, P2, L1, L2) + \mu_i - \mu^j$$

- N_w : widelane integer ambiguity
- f: Melbourne-Wübbena linear combination
- P_1 , P_2 : pseudorange
- L_1 , L_2 : phase measurements
- μ_i : widelane biases for receiver i (solved together with N_w)
- μ^j : widelane biases for satellite j (taken from the GRG products)

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Processing and Practical Application of IPPP

Zero-difference ionosphere-free

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 L_2}{\gamma - 1} =$$

$$cT_c + w - \lambda_c N_1 + \frac{\lambda_2 N_w}{\gamma - 1} + c\Delta h$$

- c: velocity of light
- T_c : coordinate time of propagation of the signal (including all delays)
- Δh: clock difference (station-satellite)
- L_1 , L_2 : phase measurements (in cycles)
- λ_i: wavelengths
- $\lambda_c = (\gamma \lambda_1 - \lambda_2)/(\gamma - 1)$ with $\gamma = (\lambda_2 / \lambda_1)$ (1.647 for GPS, 1.793 for Galileo)
- W: wind-up effect (in meters)

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Advancements and Operational Aspects of IPPP

WRB steps

Not full cycle

Change of the phase bias (receiver reboot)

Continuous link not straightforward

Prairie analysis

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Advancements and Operational Aspects of IPPP

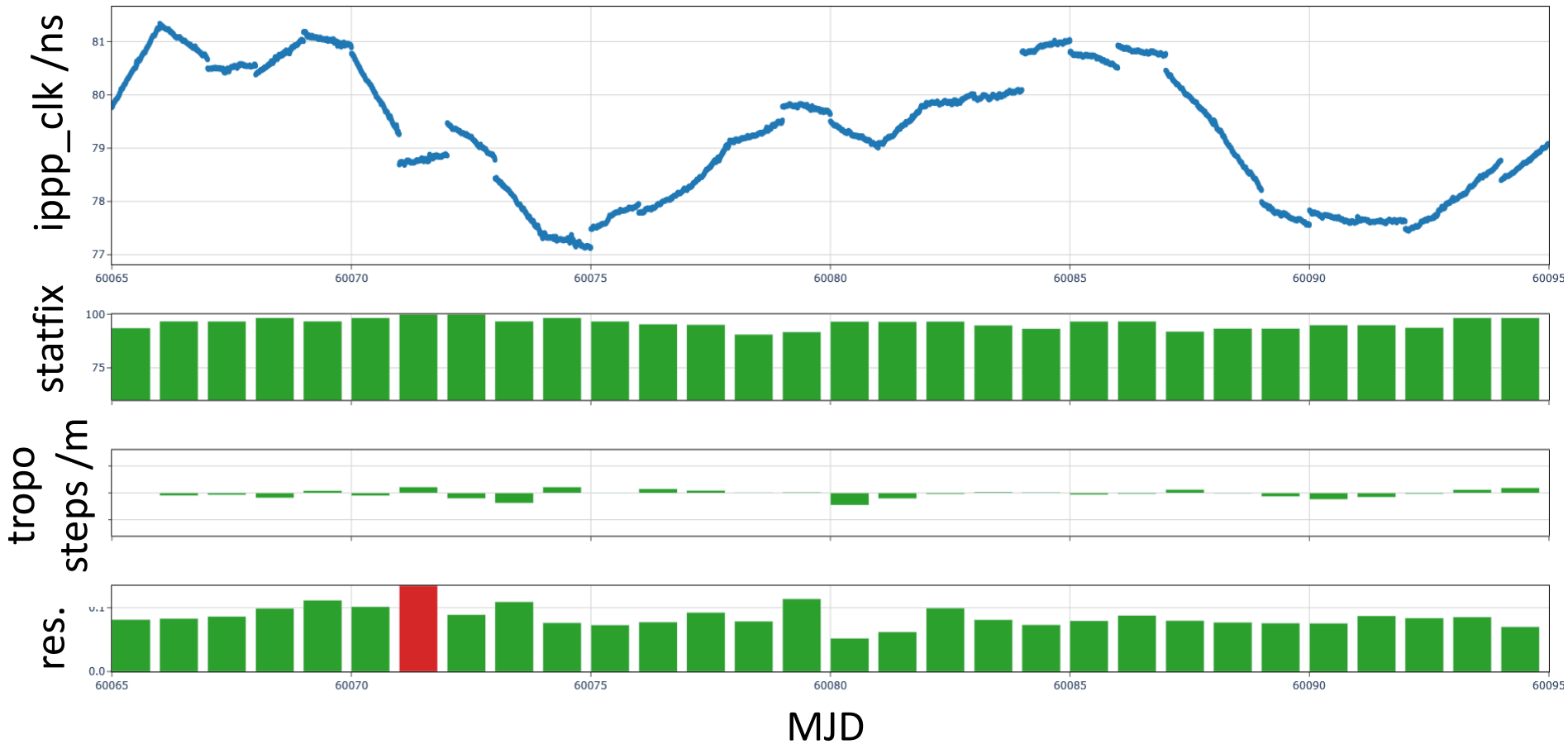
Narrow-lane ambiguities

Statfix < 90%

Misidentified ambiguities (eclipsing satellite)

Solve: removing some passes

GINS analysis – OP73



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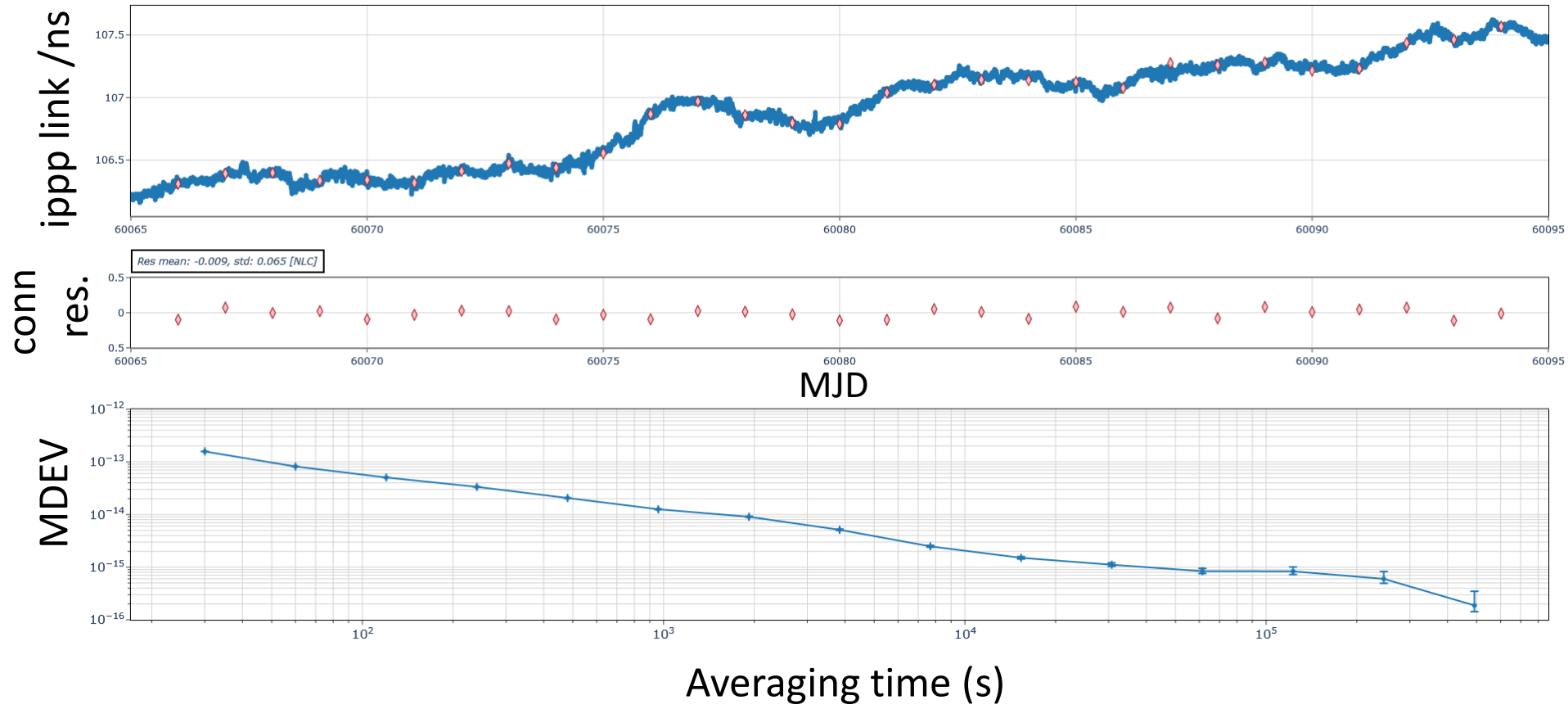
Advancements and Operational Aspects of IPPP

Day boundary step, missing data…

Steps > 100ps

Add a reset or remove period

Link analysis – PTBB - OP73



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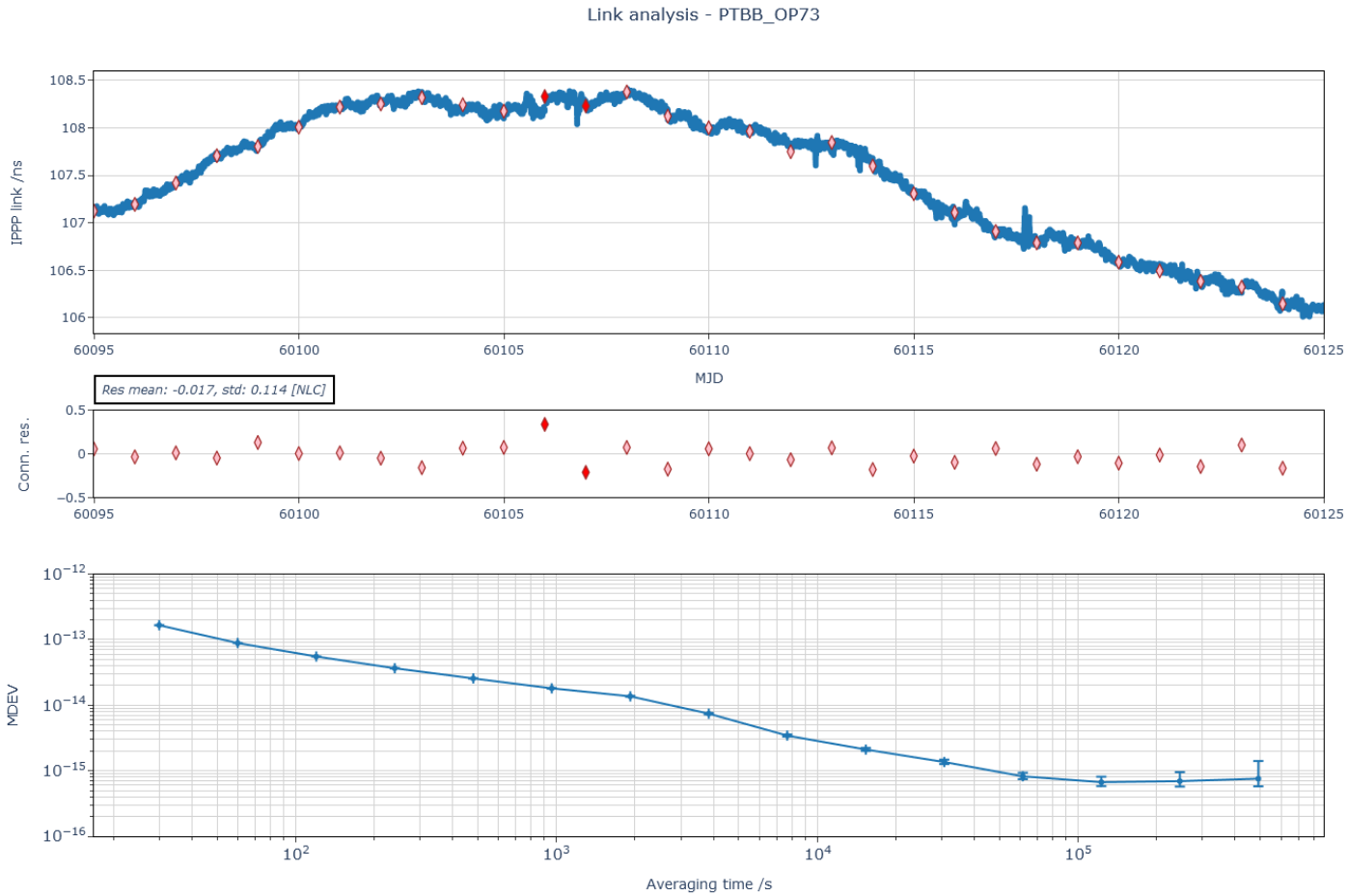
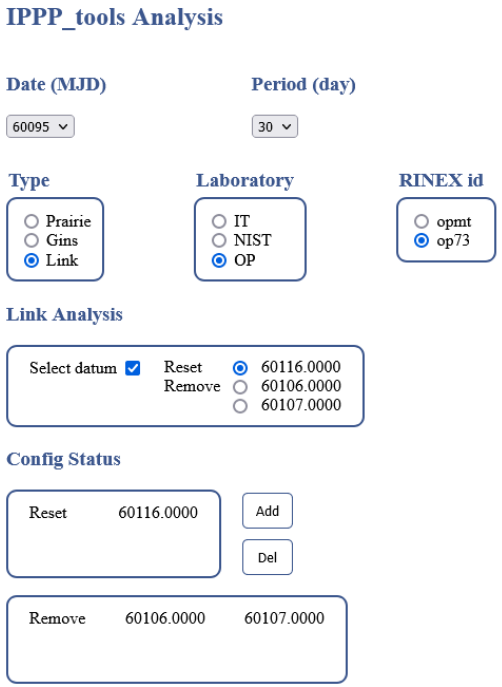
Advancements and Operational Aspects of IPPP

Local server

- HTML plot enhanced with GSL
- Interacting analysis (zoom, reset and remove period output file)





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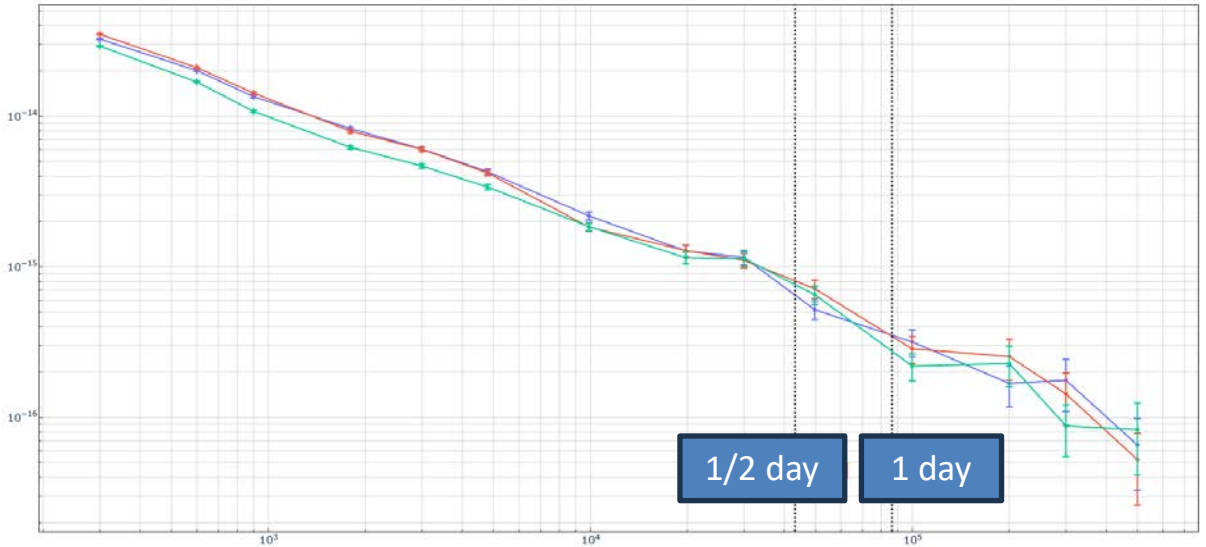
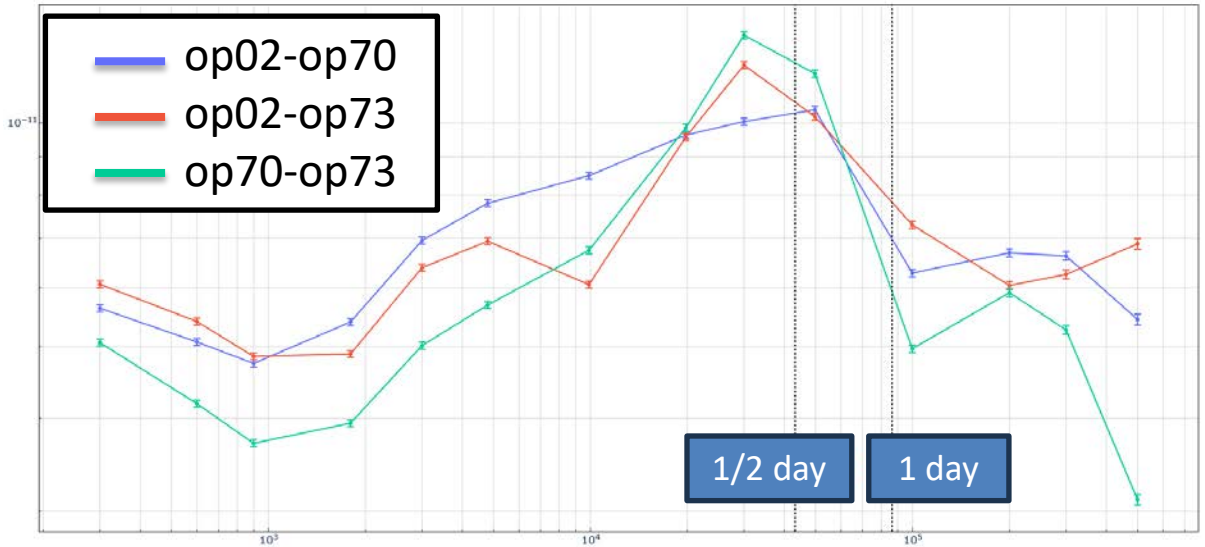
Advancements and Operational Aspects of IPPP

Allan deviation



Averaging time (s)

Time deviation



Averaging time (s)

Rinex file identifier	Model
OP02	Z-XII3T
OP70	PolaRx5TR
OP73	PolaRx5TR

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Phase Jump Detection

Kalman filter algorithm

$$\hat{\boldsymbol{X}}[n|n-1] = \boldsymbol{\Phi}[n|n-1]\hat{\boldsymbol{X}}[n|n-1]$$
$$\boldsymbol{\Gamma}[n|n-1] = \boldsymbol{\Phi}[n|n-1]\boldsymbol{\Gamma}[n|n-1]\,\boldsymbol{\Phi}^T[n|n-1] + \boldsymbol{Q}$$

$$\boldsymbol{\nu}[n] = \boldsymbol{Z}[n|n-1] - \boldsymbol{H}\hat{\boldsymbol{X}}[n]$$
$$\boldsymbol{\sigma_\nu}^2[n] = \boldsymbol{H}\boldsymbol{\Gamma}[n|n-1]\boldsymbol{H}^T + \boldsymbol{R}$$
$$\boldsymbol{K}[n] = \boldsymbol{\Gamma}[n|n-1]\boldsymbol{H}^T(\boldsymbol{\sigma_\nu}^2[n])^{-1}$$

$$\hat{\boldsymbol{X}}[n|n] = \hat{\boldsymbol{X}}[n|n-1] + \boldsymbol{K}[n]\boldsymbol{\nu}[n]$$
$$\boldsymbol{\Gamma}[n|n] = (\boldsymbol{1} - \boldsymbol{K}[n]\boldsymbol{H})\boldsymbol{\Gamma}[n|n-1]$$

- $\hat{\boldsymbol{X}}$: state estimate
- $\boldsymbol{\Gamma}$: covariance estimate
- $\boldsymbol{\nu}$: innovation
- $\boldsymbol{\sigma_\nu}^2$: innovation covariance
- $\boldsymbol{K}$: Kalman gain
- τ: sampling time with $n = t / \tau$
- $\boldsymbol{\Phi}$: transition matrix
- $\boldsymbol{H}$: observation model
- $\boldsymbol{R}$: measurement noise (phase noise)
- $\boldsymbol{Q}$: state equation noise (WFN, RWFN, drift)

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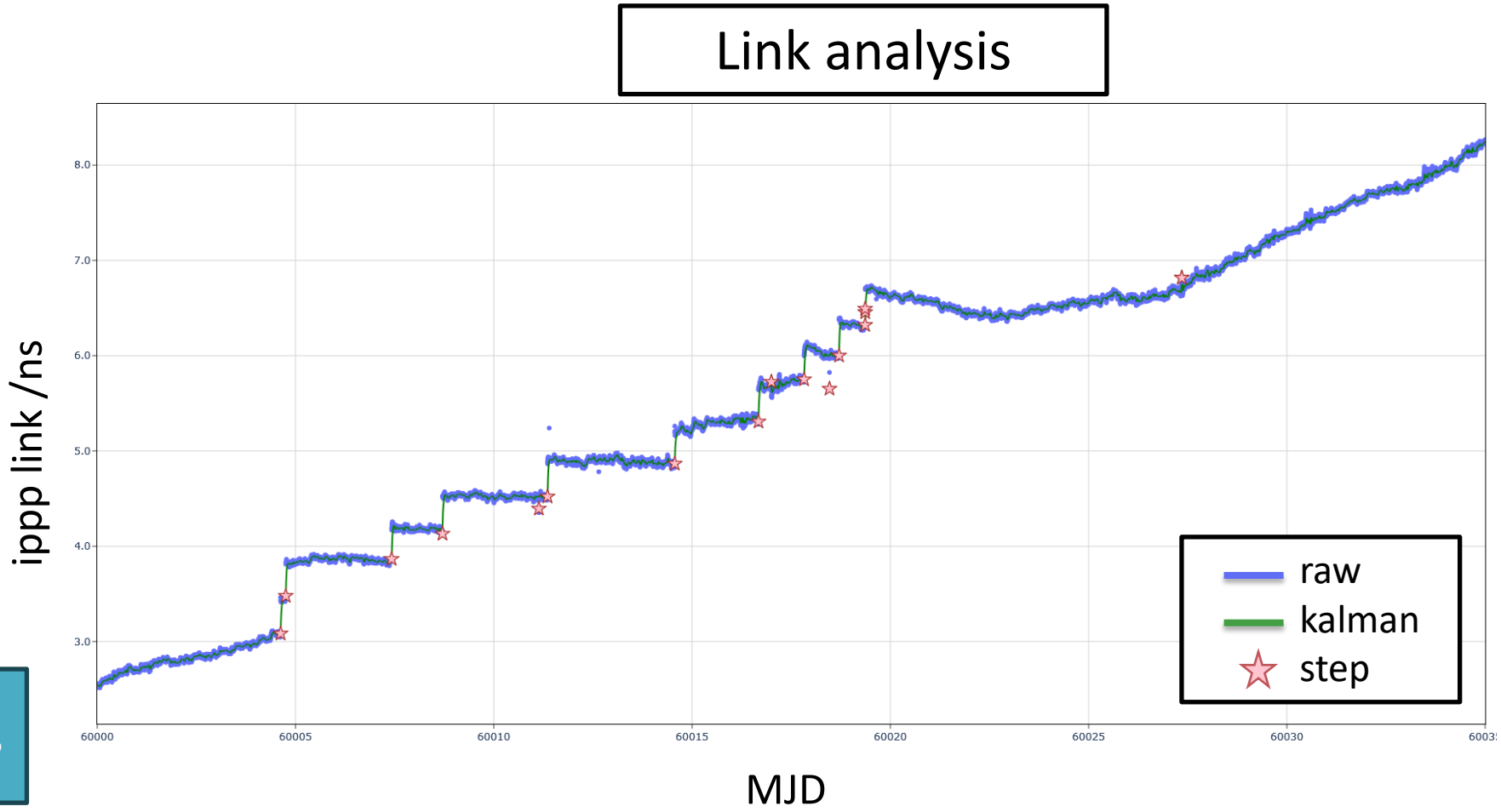
Phase Jump Detection

Time step detected

$$|\boldsymbol{\nu}[n]| > k\boldsymbol{\sigma}_{\boldsymbol{\nu}}[n]$$

- *k:* step threshold factor

Post processing analysis



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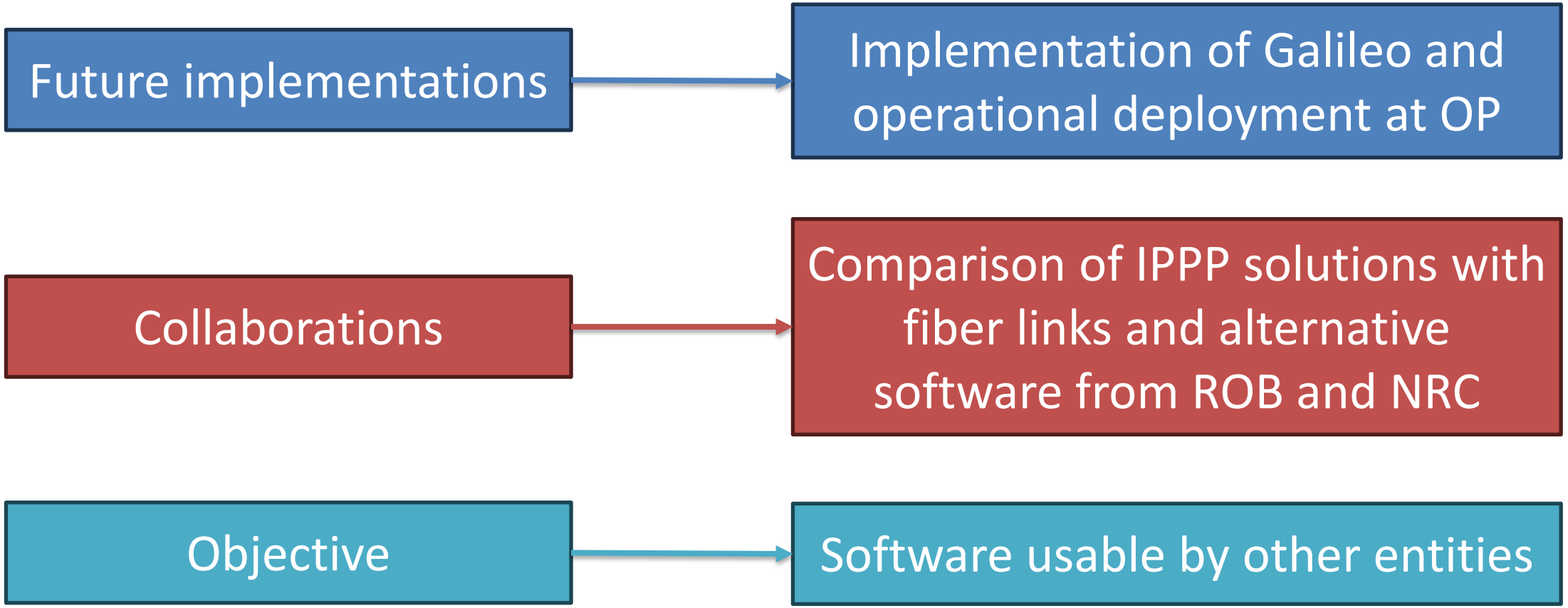
More details at: *https://theses.hal.science/tel-04083649*

Future Implementations and Collaborations



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